NON-PROVISIONAL PATENT APPLICATION

CROSS REFERENCE TO RELATED APPLICATIONS

The application claims benefit under 35 U.S.C. 119(e) from United States

Provisional Application number 60/268,096 filed on February 12, 2001.

5   ## FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

None.

TITLE

A Reduced Component Drive Circuit

BACKGROUND OF THE INVENTION

10   ### 1. Field of the Invention

The present invention generally relates to a circuit capable of driving electrical

loads. The invention specifically described is a circuit that develops a commanded DC or AC

signal from the high-frequency AC output voltage of a piezoelectric transformer.

2. Related Arts

15   A conventional power distribution circuit, as shown in Figure 1a, steps-up and

steps-down AC voltage via an electromagnetic transformer wherein primary and secondary

windings are electromagnetically coupled to a magnetic core. Both windings and magnetic

core limit miniaturization of such devices.

A conventional piezotransformer-based distribution circuit, as shown in Figure

20   1b, also provides for voltage step-up and step-down. More specifically, a Rosen transformer

excites a piezoelectric element at resonance frequency with an electrical input at one end of

the element generating a mechanical vibration, thereafter converting mechanical vibrations

into electrical voltage at a second end of the element. Piezoelectric transformers are smaller, lighter, and more efficient than conventional electromagnetic devices, however constrained to a limited operating frequency below that of electromagnetic transformers.

Higher frequency piezoelectric transformers are possible. Such devices achieve both higher operating frequency and higher power density than conventional Rosen transformers via a thickness extensional vibration mode. The resultant device operates at multiple voltage levels, since output voltage is dependent on the thickness ratio between individual layers along first and second ends of the piezoelectric element.

The output from a piezoelectric transformer has parallel capacitance and a capacitive load. Therefore, neither output nor load are directly switchable into the other except with an intervening element, typically an inductor to maintain efficiency. The related arts transform the high-frequency output from a piezoelectric transformer to DC voltage via a bridge rectifier and a fairly large capacitor. DC voltage is applied as a power supply for a switching amplifier to drive the load, again requiring a filter inductor, an inverter circuit and a feedback circuit.

Much of the complexity, bulk, and weight in the related arts is avoided by switching the high-frequency AC output from the piezoelectric transformer, also called the driving waveform, into the load at precisely the instant when the driving waveform crosses the present voltage value on the load and switching the load out when the driving waveform reaches the desired voltage. Thereafter, the switch is opened and the reactance of the load or an addition output capacitor element holds the voltage until the next switching cycle. A single bilateral switch is required.

An object of the present invention is to provide a smaller, lighter, and less complex circuit capable of driving electrical loads. A further object of the present invention is to provide a circuit capable of developing an AC voltage signal input from the high-frequency AC output of a piezoelectric transformer without capacitors or inverter.

<center>**SUMMARY OF THE INVENTION**</center>

The present invention is a drive circuit functionally distinct from conventional linear and switching drives and representing a new device called a trasversion or transconverter device. The invention is comprised of several high-frequency comparators and at least one bilateral switch. The invention converts one or more high-frequency output voltage signals from a piezoelectric transformer to low-frequency voltage signals, examples including but not limited to sinusoidal, sawtooth, ramp, and square waves, at the output amplitude voltage. The circuit switches a high-frequency AC voltage output from a piezoelectric transformer, also referred to as the driving waveform, into the load at precisely the instant when the driving waveform crosses the present voltage value on the load, and switches it out when the driving waveform reaches the desired voltage. Thereafter, the switch is opened and the reactance of the load or an additional output capacitor element holds the voltage until the next switching cycle. The circuit functions without inverter and regulation sections required in the related arts.

The circuit is applicable to various piezoelectric transformer sections wherein a high-voltage AC signal and a low-level supply are separately provided. For example, the present invention is applicable to a conventional piezoelectric transformer, a piezoelectric transformer coupling with high-level and low-level "winding" outputs, and a dual piezoelectric

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transformer.

Several advantages are offered by the present invention. The invention is smaller, lighter, less costly, and more reliable than the related arts due to the elimination of iron core/ferrite transformer and amplifier. The invention eliminates large capacitors and invert

5   section in the related arts. The invention is a modular design readily adaptable to a wide range of current-voltage output characteristics and waveforms. The invention generates an extremely low EMI/RFI signature and has a wide thermal excursion operating capability. The invention is widely applicable in such items as flourescent lighting systems, backlit lighting systems, computer electronics, and active materials and devices.

10   **BRIEF DESCRIPTION OF THE DRAWINGS**

The invention will now be described in more detail, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 describes power distribution schemes found in the related arts.

Figure 2 is a schematic diagram showing present invention with piezoelectric transformer.

15   Figure 3 is a block diagram showing signal conditioning circuit coupled to input and output elements.

Figure 4 is a functional description of the present invention.

Figure 5 is a circuit diagram showing preferred embodiment comprised of four analog comparators and a MOSFET switch.

20   Figure 6 illustrates transconversion of high-frequency AC voltage signal from a piezoelectric transformer to desired voltage signal at an electrical load.

Figure 7 illustrates transconversion of high-frequency DC voltage signal from a piezoelectric

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transformer to desired voltage signal at an electrical load.

Figure 8 is a voltage-time plot for output waveform from preferred embodiment.

Figure 9 is an enlarged view of voltage-time plot showing stepwise waveform.

Figure 10 is diagram showing a plurality of circuits arranged forming a single power distribution system.

NUMERICAL REFERENCE

1 Power source

2 Piezoelectric transformer

3 Drive circuit

4 Input side

5 Output side

6 High-frequency signal

7 Reference waveform

8 Output signal

10 Comparator circuit

12 Power distribution system

20 Power supply

21 Bulk converter

22 power storage element

23 dedicated element

24 Output side connection

25 AC generator

26 piezotransformer

27 Drive circuit

28 Supply power waveform

29 High-frequency signal

5   30 Output signal

50 Crossover point

51 Leading edge segment

52 Trailing edge segment

53 Desired voltage waveform

10   54 High-frequency AC signal

61 Reference voltage

62 Actual voltage

63 Actual voltage

64 Crossover point

15   65 Trailing edge segment

67 Desire voltage waveform

68 High-frequency DC signal

69 Actual voltage

X1 Comparator

20   X2 Comparator

X3 Comparator

X4 Comparator

L1 Load

S1 Switch

S2 Switch

DESCRIPTION OF THE INVENTION

5   The present invention facilitates AC rectification, as well as DC rectification of

AC or DC power. The described invention is quite distinct from the related arts where

rectification is provided on the output side only. Multiple transconverters supply both

separate AC voltage signals and DC voltage signals using the same level-shifting piezoelectric

transformer. Elimination of traditional passive filter components allows manufacture of the

10   transconversion device as a foundry solid state component.

Figure 3 shows the present invention, namely a drive circuit 3, electrically coupled

at an input side 4 to a power source 1 and a piezoelectric transformer 2, and at an output side

5 to one or more loads L1. The power source 1 energizes a piezoelectric transformer 2 with

a high-frequency, low voltage at one end thereby producing a high-frequency signal 6 with

15   stepped-up voltage at the other end. A very-high-frequency chopper device conditions power

from the power source 1. Power supplies and chopper devices comprising the power source

1 are readily understood by one in the art. Thereafter, the high-frequency signal 6 with

stepped-up voltage is communicated to the drive circuit 3 where it is modified and electrically

communicated to one or more loads L1 at the output side 5. Loads L1 include electrical

20   devices as understood in the art, examples including capacitive and transductive elements.

Conventional piezoelectric transformers 2 such as the TRANSONER® are

manufactured by Face International Corporation of Norfolk, Virgina. The self-contained

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implementation of the invention requires either a multi-tap piezoelectric transformer 2 or two separate piezoelectric transformers 2. Figure 2 provides a block diagram for the present invention coupled to a multi-tap piezoelectric transformer 2.

Figure 4 graphically describes functionality of the drive circuit 3. In this example, the drive circuit 3 is comprised of a comparator circuit 10 composed of a plurality of comparators electrically arranged and connected and thereafter electrically connected about a bidirectional switch S1. The comparator circuit 10 is comprised of signed components thereby facilitating both stepwise increase and decrease of voltage into the load L1. The comparator circuit 10 is electrically connected to a switch S1 regulating current flow from the piezoelectric transformer 2 to the load L1. An optional second switch S2 is provided to dump charge from the load L1. Dual switch S1, S2 embodiments are driven in opposite phase and charge direction relative to the load L1.

Drive circuit 3 generates an output signal 8 having the form of a reference waveform 7 by selectively passing portions of the high-frequency signal 6 from the piezoelectric transformer 2 to the load L1. The comparator circuit 10 receives voltage data about the switch S1 and compares this to the reference waveform 7. The comparator circuit 10 OPENS and CLOSES the switch S1, referred to as the condition, thereby passing only that portion of the high-frequency signal 6 required to increase or decrease voltage as desired in the output signal 8.

Figure 5 shows a four comparator X1, X2, X3, X4 embodiment of the drive circuit 3. Switch S1 condition is controlled by a standard TTL or CMOS circuit with comparator X1, X2, X3, X4 outputs, namely VA, VB, VC, and VD as inputs, and the switch

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S1 drive signal as output. Switch S1 condition is determined from four parameters. First, whether the next voltage along the output signal 8, for example gain times reference signal 7, is higher or lower than the present voltage along the output signal 8. Second, whether the high-frequency signal 6 crosses the next voltage. Third, whether the high-frequency signal 6

5   crosses the present voltage. Fourth, whether the high-frequency signal 6 is increasing or decreasing.

High-speed sampling by the comparators X1, X2, X3 , X4 is required to identify all four conditions. The first three parameters are determined using the corresponding voltages as inputs to the comparators X1, X2, X3. In practice, the desired output voltage is

10   determined by the input voltage, and the high-frequency signal 6 and the present voltage are divided down to the same level. Voltage dividers determine the voltage gain of the amplifier, while the maximum output of the high-frequency signal 6 determines amplitude. The fourth parameter is determined by passing the high-frequency signal 6 through an attenuating differentiator, preferable filtering high-frequency noise, where the resulting waveform and

15   zero are inputs to a fourth comparator X4. Table 1 summarizes representative values for components in Figure 5.

Multi-tap piezoelectric transformer 2 embodiments include an AC signal as an input and a plurality of AC voltages as output. In preferred embodiments, a filter capacitor is provided at the output side 5 to maintain voltage between opening and closing of the switch

20   S1. Drive circuit 3 components as well as single or dual MOSFET type swtiches S1, S2 are readily integratable at the foundry level. A wide range of voltage outputs are achievable by replacing the piezoelectric transformer 2.

The switch S1 may be comprised of a power MOSFET, a small floating power supply, an optocoupled driver, and four diodes, as shown in Figure 5. Output from the piezoelectric transformer 2 is identified as V1 and consists of a sine wave.

Figure 6 graphically describes the construction of a desired voltage waveform 53 from a high-frequency AC signal 54 generated by a piezoelectric transformer 2. The desired voltage waveform 53 is comprised of a rising portion and a falling portion about a crossover point 50. Rising portions of the desired voltage waveform 53 are produced by selecting the leading edge segment 51 from the high-frequency AC signal 54. Falling portions of the desired voltage waveform 53 are produced by selecting the trailing edge segment 52 from the high-frequency AC signal 54.

Figure 7 graphically describes the construction of a desired voltage waveform 67 from a high-frequency DC signal 68 generated by a piezoelectric transformer 2. Actual voltage 69 typically includes regions of the waveform within tolerance, actual voltage 62 in Figure 7, and regions of the waveform out of tolerance, actual voltage 63 in Figure 7, about a crossover point 64. When the waveform is out of tolerance, trailing edge segments 65 from the high-frequency AC signal 68 are selected to increase the load voltage.

Figure 8 shows an exemplary output signal 8 generated from a high-frequency signal 6. Figure 9 provides a detailed view of the output signal 8 highlighting the stepwise feature of the output voltage. Horizontal steps occur when the switch S1 is OPEN. Vertically increasing and decreasing steps result when switch S1 is CLOSED.

Figure 10 shows a block diagram comprised of a plurality of paired piezoelectric transformers 2 and circuits 3 forming a power distribution system 12. A power supply 20

generates, collects, or communicates power from one or more sources, including but not limited to thermal, photovoltaic, AC line and DC line, to a bulk converter 21 where it is converted to a clean DC level power, and thereafter communicated to a power storage element 22, one example including a battery. Thereafter, power is communicated to two or more dedicated elements 23. In an alternate embodiment, power is directly communicated from power supply 20 to dedicated elements 23.

Dedicated elements 23 are comprised of a high-frequency AC generator 35 which converts DC power from the storage element 32 or power supply 20 to AC power as shown by supply power waveform 28, a piezotransformer 26 which transforms the AC power as shown high-frequency signal 29, and a drive circuit 27 which modifies the signal from the piezotransformer 26 to an output signal 30 compatible with the power requirements of the end device. For example, the drive circuit 27 might modify the signal from the piezotransformer 26 to a sinusoidal, sawtooth, square or other wave required for use by an electrical device. Each dedicated element 23 uniquely provides for the power needs of a load L1 coupled to the output side connection 24 of the drive circuit 27.

The description above indicates that a great degree of flexibility is offered in terms of the present invention. Although embodiments have been described in considerable detail with reference to certain preferred versions thereof, other versions are possible. Therefore, the spirit and scope of the appended claims should not be limited to the description of the preferred versions contained herein.

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TABLE 1

Component	Description
Resistor R1	1,000 ohms
Resistor R2	100,000 ohms
Resistor R3	1,000 ohms
Resistor R4	100,000 ohms
Resistor R5	1,000ohms
Resistor R6	1,000 ohms
Resistor R7	1,000 ohms
Resistor R8	1,000 ohms
Resistor R9	1,000 ohms
Resistor R10	1,000 ohms
Resistor R11	1,000,000 ohms
Capacitor C1	1 μF
Capacitor C2	1 pF
Comparator X1	NE527, Phillips Semiconductors Co.
Comparator X2	NE527, Phillips Semiconductors Co.
Comparator X3	NE527, Phillips Semiconductors Co.
Comparator X4	NE527, Phillips Semiconductors Co.

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